The slope of Oak Creek is approximately 3.5 fpm, while the slope of North Oak Creek averages 5.6 fpm.

The slope of Ash Hollow Ditch is approximately 3 fpm.

Lancaster County is one of the three counties in Nebraska expected to have a growth rate in excess of 20 percent in the next decade. As a result, the City of Lincoln will probably enlarge its zoning jurisdiction through annexation of outlying areas of the County. These areas will then change in land use from the present agricultural to residential or commercial. County and regional planners must be aware of the flood potential and must manage floodplain development through the regulations and ordinances suggested by this study, in order to mitigate or prevent damages due to flooding.

With the exception of a few farm buildings, the majority of the floodplain areas in this study are void of residential and commercial development. Future development should be confined to areas of high ground, or elevated fill within the floodway fringe.

In the Village of Bennet, residential development is likely to continue on high ground and other minimally flood-prone areas. The existing floodplain development is agricultural. There is a natural basin divide which separates the Little Nemaha River from the Unnamed Tributary that runs south and east to approximately 1,200 feet east of Highway 43. This area east of Highway 43 has been recently used for the disposal of solid waste.

The Village of Firth is primarily an agricultural community. Commercial development is primarily located on Main Street, with residential development expanding to the north and east of town. The development within the floodplains is mainly residential within the corporate limits and open land outside the corporate limits.

The City of Hickman is primarily an agricultural community, with the grain elevator being the major industry. Commercial development is likely to continue near the center of town (Main and Locust Streets). Residential development is likely to continue on high ground to the north and east of town.

Development within the floodplain is sparse, consisting primarily of agricultural and residential use. A sewage treatment plant was also constructed in the 100-year floodplain of Hickman Branch.

Development in the Village of Raymond is confined to the area east of the railroad and out of the floodplain. New development is expected to be on high ground to the east of town or on elevated fill.

The City of Waverly is experiencing a rapid growth rate (an approximately 30-percent increase in population in 10 years) and, as a result, areas near floodplains are being developed.

2.3 Principal Flood Problems

Low-lying areas of the County are subject to periodic flooding from the overflow of Salt Creek and its tributaries. The most severe flooding has occurred in the late spring and early summer as a result of snowmelt, heavy thunderstorm rainfall, ice jams, or combinations of the above.

Flood records for the Salt Creek basin generally combine the tributary data with the mainstem data. Thus, separate tabulations for Ash Hollow Ditch, Stevens Creek, Oak Creek, North Oak Creek, Middle Creek, and Haines Branch are not available. Completion of the Salt Creek project of Federal flood control dams and reservoirs has affected the historic flood frequency and magnitude in the study reaches. However, these improvements have not eliminated completely the flood problem throughout the County. Offsetting a part of the protection gained will be the increase in runoff resulting from anticipated additional development in the valleys.

Since 1900, 100 floods have been recorded along Salt Creek and its tributaries in Lincoln and vicinity. Of these, 17 are classed as major, 30 as moderate, and 49 as minor. Two floods, those of July 6, 1908, and May 8 and 9, 1950, reached catastrophic proportions in Lincoln, and four others inflicted heavy damage. Reliable records on loss of life, available only since 1942, indicate 13 deaths have been attributed to flooding: one in 1942, nine in 1950, and three in 1963. Lives were reported lost in the 1908 flood, but accurate data on the number and circumstances are not available. Discharge data are available only for Salt Creek. The maximum discharge in Lincoln is the estimated 30,650 cubic feet per second (cfs) for the July 6, 1908 flood. Recorded peak discharges are 27,800 cfs for the May 8 and 9, 1950, flood; 28,200 cfs for the June 1 and 2, 1951, flood; and 21,600 cfs for the June 24 and 25, 1963, flood (Reference 5).

The recurrence intervals of past major or recent floods are estimated as follows (Reference 10):

Month-Year	Discharge (cfs)	Recurrence Interval (Years)
July 1908	30,650	32
May 1950	27,800	24
June 1951	28,200	26
June 1963	21,600	14
September 1977	7,600	2
March 1978	6,110	1.7
May 1979	8,710	2.3

The Salt Creek flood of May 8 and 9, 1950, is typical of the extreme floods occurring in the study areas. This flood resulted from a severe storm over southeastern Nebraska. Rainfall in excess of 11 inches was recorded in the southern portion of the basin, and a 6-hour accumulation exceeding 5.5 inches was reported over a 1,000-square-mile area. Nearly 20,000 acres of basin lands were flooded, and nine lives were lost. In Lincoln, approximately 600 homes, 80 commercial establishments, railroad yards, and other

improvements were flooded. Basin damages were estimated at $2,880,000, including $1,643,000 occurring within Lincoln. A repeat of this storm, with the present development in the basin, would result in greater damages and possibly a greater loss of life (Reference 5). Figures 1 through 6 show flooding in Lancaster County.

In the Villages of Bennet and Firth and the City of Hickman, floodwater damages to crops, pastures, other agriculture properties, roads, and bridges are the principal watershed problems. Storms that may produce these damages occur most frequently during June and July when crops are most susceptible to damage. Agricultural properties damaged by floodwater include fences, farm buildings, and machinery. Flood damage to roads consists of removal of surface materials and erosion of fills. Losses to bridges are reflected as increased maintenance and replacement cost that is directly attributed to floodwater (Reference 4).

Approximately 3.1 miles of railroad track in the Village of Bennet are subject to some degree of floodwater damage from the 100-year or greater frequency storm event. Losses to those facilities consist of fill and ballast removal, track damage, and interruption of service and/or rerouting of scheduled trains.

Low-lying areas of the Village of Bennet are subject to periodic flooding from the Little Nemaha River and its Unnamed Tributary. Although there are records of floods downstream of Bennet at Unadilla, Syracuse, and Auburn, there are no records of floods as far upstream as Bennet. There are four bridges in the Bennet study area that constrict the flow and produce shallow, low-velocity ponding at the edges of the floodplain (Reference 11).

The most recent major flood in the City of Hickman occurred in June 1963, when $98,000 of damage was done by Hickman Branch floodwaters. Other major floods occurred on July 10, 1950; May 8, 1950; and July 5, 1908. Construction of the Wagon Train Lake Dam and the Stagecoach Lake Dam has helped flooding problems downstream at Hickman (Reference 7).

Portions of the City of Lincoln lie in the floodplains of Salt Creek, Oak Creek, Middle Creek, Antelope Creek, Beal Slough, Haines Branch, Cardwell Branch, Elk Creek, Lynn Creek, Deadman's Run, and Little Salt Creek. Flooding along Salt Creek and Oak Creek is of long duration with ample warning time prior to the peak. Little Salt Creek, Middle Creek, and Haines Branch have smaller drainage areas with shorter flood duration and less warning time prior to the peak. Flooding on Antelope Creek, Beal Slough, Cardwell Branch, Elk Creek, Lynn Creek, Stevens Creek, Stevens Creek Tributary, and Deadman's Run is of short duration with little warning time prior to the peak.

Specific flood records on Oak Creek are confined to two minor floods on June 15, 1945, and June 1, 1947. The damage from each flood occurred mainly to crops, farmsteads, roads, bridges, and railroads. Other floods have occurred on Oak Creek; however, because of the rural nature of Oak Creek prior to the construction of flood control works in the Oak Creek basin, floods on Oak Creek were not documented.

Floods on Antelope Creek are known to have occurred in 1908, 1910, 1940, 1950, 1951, 1952, 1957, and 1958. The floods of June 14, 1951, and July 9 and 10, 1958, caused significant residential and commercial property damage in the Antelope Creek floodplain.

FIGURE 1 - Channel through undeveloped area.

FIGURE 2 - Typical bridge damage.

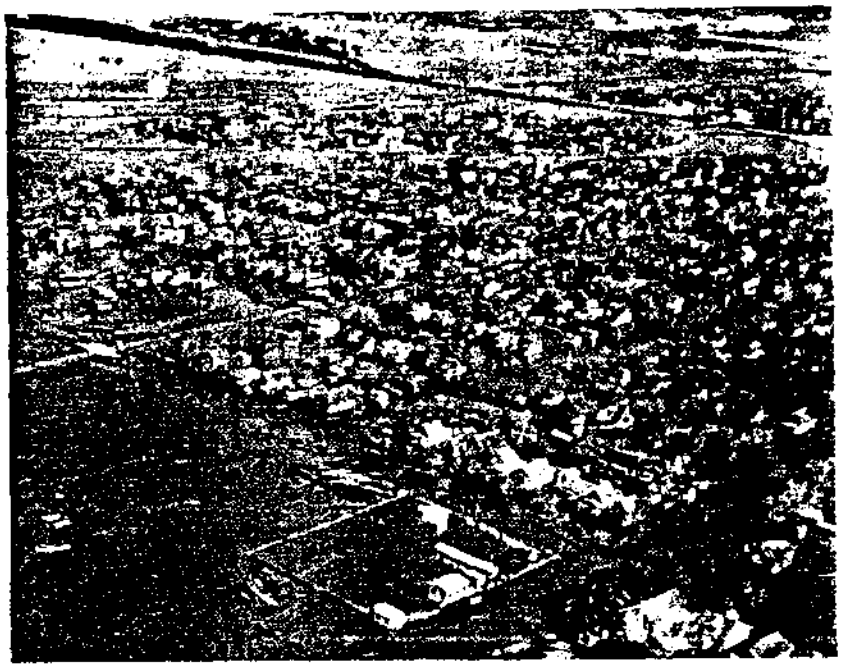

FIGURE 3 - Flooding in residential area south of 'O' Street in Lincoln. Salt Creek flood of May 8-9, 1950.

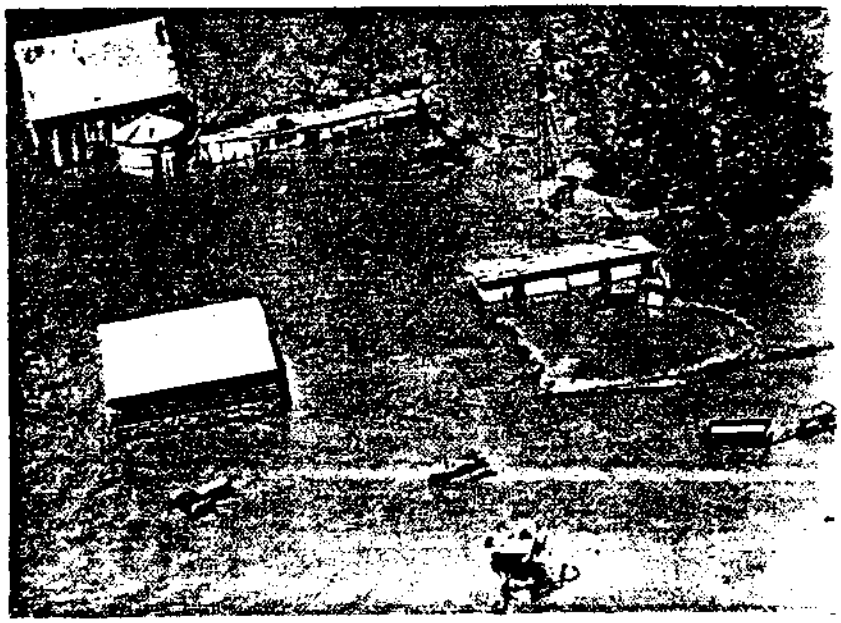

FIGURE 4 - Typical rural damage. Salt Creek flood of May 8-9, 1950.

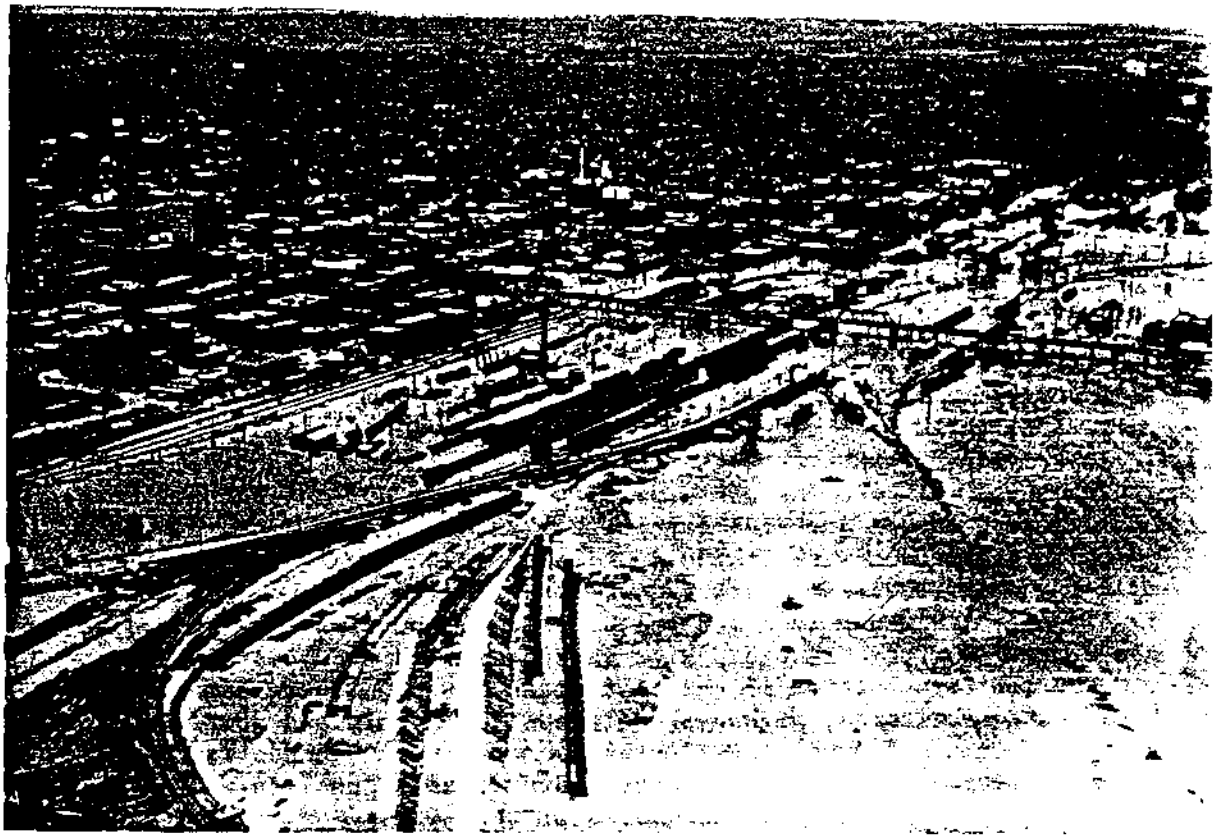

FIGURE 5 - Urban flood damage at Lincoln near 'O' Street.

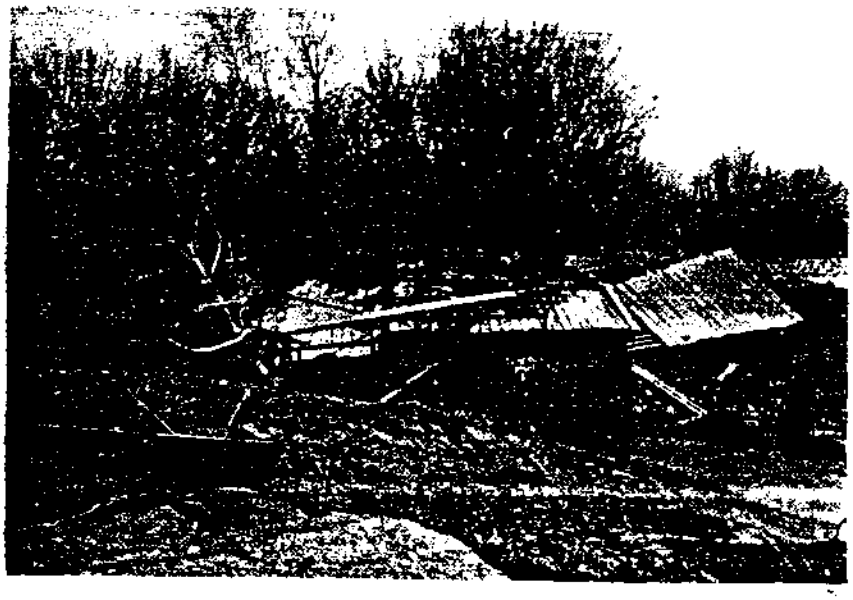

FIGURE 6 - Bridge damage. Salt Creek flood of May 8-9, 1950.

The remainder of the tributary streams in the City of Lincoln study did not have a separate flood history available. Although flooding has occurred in the past, specific flood records are not available for these tributaries. The rural nature of these streams resulted in relatively little flood damage when compared with flooding damage along Salt Creek.

In the City of Waverly, a severe rainstorm caused flooding on Ash Hollow Ditch on June 14, 1964 (Reference 12). No discharge or damage estimates are available. Completion of the Salt Creek Federal flood control project has affected the historic flood frequency and magnitude in the study reach of Salt Creek. Channel improvements and new culverts have decreased the flood problem from Ash Hollow Ditch within the corporate limits of the City of Waverly. Offsetting the protection measures currently in place is the increasing rate of urbanization in the upper part of the watersheds. Urbanization increases flood peaks by decreasing the amount of time required for water to reach downstream sections of a watershed and by decreasing the amount of water detained or infiltrated into the soil.

The history of flooding within the Salt Creek basin, which contains Oak Creek and the Village of Raymond, indicates that flooding may occur in any season except the winter months of December through February. The majority of major floods have occurred during the spring and early summer months. Snowmelt can produce high stream stages and minor overbank flooding. However, the major source of flooding is from runoff during or immediately following severe thunderstorms. Runoff is rapid and with little warning except the thunderstorm itself. Velocities in and near the creek channels are high. The lack of warning time and the high flow velocities tend to make evacuation of movable property impractical or even dangerous.

Flood history on Oak Creek is meager. However, in June 1963, the Oak Creek Watershed experienced a severe flood-producing storm. Average excess rain depths ranged from 1 inch in the southwest to 7.8 inches in the north. Crest-stage flood records show that the storm produced peak flows of 27,500 cfs at Agnew and 21,600 cfs at the mouth of Oak Creek (Reference 5). A discharge of 25,900 cfs was estimated at Raymond. This discharge translated to a return period of 100 years based on discharges to 1963 (without Branched Oak Dam). Based on conditions in the watershed now, a discharge of 25,900 cfs would have a return period of greater than 500 years.

The flood of June 15, 1945, began during the first half of June 1945, when frequent rains over eastern Nebraska saturated the soils. On June 15, heavy rains falling on the saturated soils caused flooding on Oak Creek and other streams in southern Nebraska. The overflows inundated 3,945 areas in the Oak Creek basin between the headwaters and the Lincoln Air Park. Minor damage was sustained by crops, farmsteads, highways, bridges, a Union Pacific Railroad branch line, and the Villages of Valparaiso and Raymond. At Valparaiso, five residences and five commercial enterprises sustained basement flooding and two homes had water on the first floor. Three residential basements were flooded at Raymond. Basin damages were estimated at $146,440, of which $7,400 occurred in the urban areas. No discharge measurements were made (Reference 5).

The flood of June 1, 1947, began when frequent rains during late May 1947 saturated the basin soils and caused Oak Creek to overflow its channel, flooding lowlands between Agnew and 2 miles downstream from Raymond. Approximately 400 acres of croplands

were inundated. Damages were confined to crops, highways, and bridges. No damage estimates or discharge measurements are available (Reference 5).

Other flooding has occurred on the stream but it has been recorded as part of the Salt Creek basin total without specific reference to the tributaries involved. The bridge over Oak Creek at West Mill Road causes excessive backwater due to the superstructure being inundated and flow passing over the road in the overbanks.

2.4 Flood Protection Measures

Flood control structures, built by the USACE, that have a major impact in reducing Salt Creek and tributary flows in the area of study are Olive Creek Dam, at Olive Creek Lake on Olive Creek northwest of the Village of Hallam; Blue Stem Dam, at Blue Stem Lake on North Branch Salt Creek northwest of the Village of Sprague; Wagon Train Dam, at Wagon Train Lake on Wagon Train Creek, approximately 1.5 miles east of the City of Hickman; Stage Coach Dam, on Stage Coach Creek south of the City of Hickman; Yankee Hill Dam, on Yankee Hill Lake on Cardwell Branch east of the Village of Denton; Conestoga Dam, at Conestoga Lake on Holmes Creek north of the Village of Denton; Twin Lakes Dam, north of the City of Waverly in Saunders County; Pawnee Dam, at Pawnee Lake on Middle Creek north of the City of Lincoln; Holmes Dam, on Holmes Branch in the City of Lincoln; and Branched Oak Dam, at Branched Oak Lake on Oak Creek west of the Village of Raymond. All of these dams provide protection from the 100-year flood. Having a lesser effect on Salt Creek flows are the NRCS dams built in the upper Salt (22) and Oak (8) Creek basins. These structures were built as part of the Upper Salt Creek Watershed and North Oak Creek Watershed. The Teal Lake structure in the upper Salt Creek basin was built by the State of Nebraska. It is located in the southwest corner of the County approximately 2 miles east of the County boundary and provides some protection from flooding. The levee system developed through Lincoln also affects Salt Creek flows (Reference 13).

There has been minor channel straightening associated with road, highway, and railroad construction in the area of the Village of Bennet. Specifically, the Unnamed Tributary to the Little Nemaha River has been straightened through the Bennet Road culvert as shown on the map panels.

The NRCS is currently preparing a watershed work plan to evaluate land treatment and flood retention measures. However, sufficient progress has not been made to include the results of the plan in this study. There are no other flood protection measures affecting the village of Bennet.

The NRCS has proposed 14 floodwater-retarding structures upstream of the Village of Firth as shown in the Watershed Work Plan for the Upper Big Nemaha Watershed (Reference 14). Seven of these structures have been completed, and they control a drainage area of 5,676 acres. These structures have reduced annual floodwater damages to crops and pastures as well as flooding in the Village of Firth, but vary in the amount of protection they provide. There are no other flood protection measures affecting the Village of Firth.

Dam No. 8, Wagon Train Lake, has been constructed approximately 4 miles upstream of the City of Hickman corporate limits. Dam No. 9, Stagecoach Lake, has been constructed

approximately 2 miles upstream from the City of Hickman corporate limits. These dams control 25.3 square miles of drainage area for Hickman Branch. There have also been some minor channel improvements associated with dam, road, and railroad construction. There are no other flood protection measures affecting the City of Hickman.

A USACE levee system from Superior Street upstream to Calvert Street protects the City of Lincoln from frequent flood events along Salt Creek. Channel stabilization projects along Antelope Creek and Deadman's Run provide a small degree of flood protection.

The levee on the eastern bank of Oak Creek southwest of the Lincoln Municipal Airport is certified against the 100-year flood event. Also, the Oak Creek channel has been improved from its mouth to Interstate 80. Small levees also have been constructed along portions of this channel. The Salt Creek channel has been enlarged and levees have been constructed from Superior Street to the downstream study limit.

The Branched Oak Dam and Reservoir (a Federal flood control reservoir) provide flood control for a drainage area of 88.7 square miles of Oak Creek above Raymond. The dam is located on Oak Creek 7.9 miles upstream of the confluence of North Oak Creek. The peak flows in the channel of Oak Creek downstream of the confluence of North Oak Creek are reduced by approximately 35 percent due to the flood control provided by the dam. The estimated peak discharge in the Oak Creek Channel downstream of the dam to its confluence with North Oak Creek is 5,800 cfs. The existing channel can pass this discharge within its banks.

In addition, there are a number of NRCS dams built in the upper North Oak Creek basin above the extraterritorial limits of Raymond. These dams were considered in the analysis but have a lesser effect on the 100-year flood flow than the Federal flood control reservoir previously mentioned.

Non-structural measures of flood protection are also being used by the Village of Raymond to aid in the prevention of future flood damage. These are in the form of land use regulations adopted from the Code of Federal Regulations that control building within areas that have a high risk of flooding (Reference 15).

The City of Waverly has made two channel improvements to Ash Hollow Ditch. The first improvement involved realignment and enlargement of the existing channel to a capacity of 2,000 cfs upstream of U.S. Highway 6. This project was completed in 1971. The second improvement involved realignment and enlargement of the existing channel to a capacity of 2,000 cfs downstream of the BNRR, and replacement of the existing 4-cell, 10-foot by 6-foot box culvert under U.S. Highway 6 to accommodate a new four-lane divided highway. The new box culvert is a 4-cell, 10-foot by 8-foot box culvert.

The ordinances of Waverly take a very hard line against development by prohibiting any development within an identified floodplain (Reference 16). In addition, projects have been, and are, ongoing to contain flood flows within the channel of Ash Hollow Ditch to reclaim land previously flood prone. With this rapidly urbanizing situation, hydrology conditions within the watershed are constantly changing.

3.0 ENGINEERING METHODS

For the flooding sources studied by detailed methods in the community, standard hydrologic and hydraulic study methods were used to determine the flood-hazard data required for this study. Flood events of a magnitude that are expected to be equaled or exceeded once on the average during any 10-, 50-, 100-, or 500-year period (recurrence interval) have been selected as having special significance for floodplain management and for flood insurance rates. These events, commonly termed the 10-, 50-, 100-, and 500-year floods, have a 10-, 2-, 1-, and 0.2-percent chance, respectively, of being equaled or exceeded during any year. Although the recurrence interval represents the long-term, average period between floods of a specific magnitude, rare floods could occur at short intervals or even within the same year. The risk of experiencing a rare flood increases when periods greater than 1 year are considered. For example, the risk of having a flood that equals or exceeds the 100-year flood (1-percent chance of annual exceedence) in any 50-year period is approximately 40 percent (4 in 10); for any 90-year period, the risk increases to approximately 60 percent (6 in 10). The analyses reported herein reflect flooding potentials based on conditions existing in the community at the time of completion of this study. Maps and flood elevations will be amended periodically to reflect future changes.

3.1 Hydrologic Analyses

Hydrologic analyses were carried out to establish peak discharge-frequency relationships for each flooding source studied by detailed methods affecting the community.

Discharges were developed by the USACE, Omaha District, for the City of Lincoln Flood Insurance Study. The methodology for developing discharges is given in the following paragraphs (Reference 13):

A. General: Discharge-probability relationships for Salt Creek and tributaries were developed using the Environmental Protection Agency "Storm Water Management Model" (SWMM) (Reference 17) in combination with the USACE Unsteady Flow Model (Reference 18). Hydrographs from the SWMM were routed down Salt Creek from the downstream end of the levee system (confluence of Deadman's Run) to the downstream study limit. The resulting 100-year discharges and a selected 0.35 standard deviation were used to develop discharge-probability relationships. For the purpose of this study, zero discharges were assumed at all USACE Salt Creek dams. Table 1, "Salt Creek Basin Drainage Area," illustrates, in downstream order, the cumulative drainage area of each tributary. Columns showing controlled areas represent the amount of drainage area controlled by USACE dams. Values for cumulative controlled areas reflect the total drainage area controlled by Salt Creek tributary dams upstream of each location specified, including the controlled area on the tributary at that location.

B. Hydrologic Model: The 616-square-mile Salt Creek basin, at the downstream limit, was divided into three subbasins. The 226-square-mile area of Subbasin 1 was divided into 404 subcatchments, averaging 360 acres in size. Data for 22 NRCS dams in the Upper Salt Creek Watershed (References 19 and 20) were input into the SWMM model. Storm runoff from the areas above the dams was routed through reservoir storage and the respective dams, using the above-referenced input data. Flood peaks in most reservoir routings were very significantly reduced. Subbasin 2, consisting of 236 square miles, was divided into 521 subcatchments that average 290 acres in size. There were eight NRCS dams in the North Oak Creek Watershed that were integrated into the SWMM model. These structures also produced very significant reductions in peak discharge from the areas above the dams. Other NRCS dams were constructed in